[0029] The composite materials may be formed by densifying techniques following processes such as conventional blending, solvent-mediated reaction synthesis (SMRS) and mechanical alloying (MA). SMRS is performed by formulating and blending precursor constituents of the nominal composite formulation desired. If thermodynamically favorable, a synthesis reaction can be initiated, e.g., using an induction power heating source. The as-synthesized product may be crushed to ensure homogeneity, and subsequently densified using powder metallurgy techniques such as sintering, hot isostatic pressing or hot pressing. Mechanical alloying is performed by formulating and ball milling precursor constituents of the desired nominal composite formulation. The milling provides energy to initiate the synthesis reaction. The as-synthesized product is densified using powder metallurgy techniques such as sintering, hot isostatic pressing or hot pressing. If produced using a solvent-mediated, in situ reaction synthesis technique, such a composite may derive benefit from certain microstructural attributes known to be characteristic of the process, notably, clean matrix-particulate interfaces, single crystal reinforcement, and a broad ability to vary reinforcement size and volume fraction.

[0030] Characterization of multifunctional composite materials can be difficult due to shielding of the embedded reinforcement by the matrix. Specifically, in the case of the ferroelastic reinforced metal matrix composites, the metal matrix physically and electrically shields the ferroelastic particulates, thus prohibiting direct electrical and dimensional observations as a means of quantifying domain motion under an applied load. However, observation of the ferroelectric particulates was accomplished by measuring lattice strain, by neutron diffraction, in the matrix and reinforcement simultaneously under applied load in two orthogonal directions. The spectrometer used a horizontal load frame that is oriented such that the loading axis is 45 degrees from the incident neutron beam and the detector banks are positioned on both sides of the load frame oriented at 90 degrees relative to the load frame. The orientation of the load frame and location of the detector banks with respect to the incident beam are such that crystallographic planes which diffract into one detector bank have lattice plane (002) normals perpendicular to the loading direction and crystallographic planes which diffract into a second detector bank have lattice plane (200) normals parallel to the loading direction. Accordingly, orientation of a tetragonal unit cell will have diffraction of (002) planes into detector bank 1 and (200) planes into detector bank **2**. If the unit cell was rotated +/−90° relative to the incident beam, as would occur in twinning, then the banks into which the planes diffract would switch because of the 90° rotation of the planes normals. Thus, changes in the ratio of peak intensities of the (200) and (002) planes in a single bank are indicative of twinning.

[0031] To confirm that stress transfer from the matrix to the reinforcement leads to twinning in the reinforcement, in situ neutron diffraction patterns were collected during cyclic compression loading on a (Cu—Sn)-$BaTiO_3$30 vol. % sample. The form of the cyclic compressive loading was sinusoidal, an amplitude of 10 MPa superimposed on a constant compressive stress of 30 MPa; neutron diffraction patterns were collected for cycles **1**, **2**, **5**, **10**, **25**, and **50**. FIG. **4** shows the normalized peak intensities for the (002) and (200) planes as a function of the macroscopic stress state of the composite for cycles **5**, **10**, **25**, and **50**. Peak intensities were determined from single peak fits to neutron diffraction patterns from the +90° detector bank. In a tetragonal system such as $BaTiO_3$, changes in the ration of the (002) and (200) peak intensities with applied stress are a direct observation of deformation twinning.

[0032] FIG. **4** shows that as the magnitude of the macroscopic compressive load increases the number of (002) planes satisfying the Bragg condition decreases and the number of (200) planes meeting the Bragg condition increases; upon unloading the intensities in the two peaks return to their initial values. Over the applied stress range of −20 to −40 MPa, increasing the compressive load results in the formation of deformation twins with (002) lattice-plane-normal preferentially oriented perpendicular to the loading direction and as the compressive load is removed detwinning occurs. A linear least squares fit of the intensity as a function of stress is also shown on the figure for both planes. The slope of the lines is proportional to number of domains with a plane normal oriented such that Bragg condition is met. The slope of the (200) line is half the (002) because there are twice as many (200) planes as (002) planes and the absolute intensity changes for the (200) and (002) planes are equal, thus when the intensity is normalized slopes are different by a factor of ½. This supports the conclusion that the observed twinning/detwinning that occurs during cyclic loading, as observed by in situ neutron diffraction, leads to enhanced damping in ferroelastic reinforced metal matrix composites below the Curie temperature.

[0033] Another composite material comprising a nickel matrix and $BiTiO_3$ ferroelectric particulates was made. The composite was made by an electroplating technique referred to as electroforming. $BaTiO_3$ was suspended in a nickel-electroplating bath and as the nickel is plated onto the substrate (cathode) some $BaTiO_3$ is incorporated into the nickel structure being deposited. Coating the $BaTiO_3$ with a metal can increase the amount of $BaTiO_3$ incorporated into the nickel. The metal coating can be applied to the $BaTiO_3$ by electroless plating or other processes which can be used to deposit metal on nonconductors. FIG. **5** is a photomicrograph of the resultant Ni—$BaTiO_3$ composite material.

[0034] The present composite materials can be used in any applications where strength and damping are important system requirements. A great flexibility in synthesis routes and processing allows for a high degree of composite system design. Through variances in reaction system stoichiometry and chemistry, these composites can be tailored to meet a great number of performance criteria including corrosion, fatigue, and creep resistance, and mechanical property levels such as high hardness, stiffness, and yield strengths. Numerous potential applications thus exist that will only fully be realized when design problems present themselves and material systems are created to solve them. Examples might include numerous individual components on vehicles (aircraft, automobile, military, marine), marine propellers, building materials, etc.

[0035] Whereas particular embodiments of this invention have been described above for purposes of illustration, it will be evident to those skilled in the art that numerous variations of the details of the present invention may be made without departing from the invention as defined in the appended claims.